OFFICE OF NAVAL RESEARCH
Contract N 000 14-75-c-0486

SCIENTIFIC REPORT

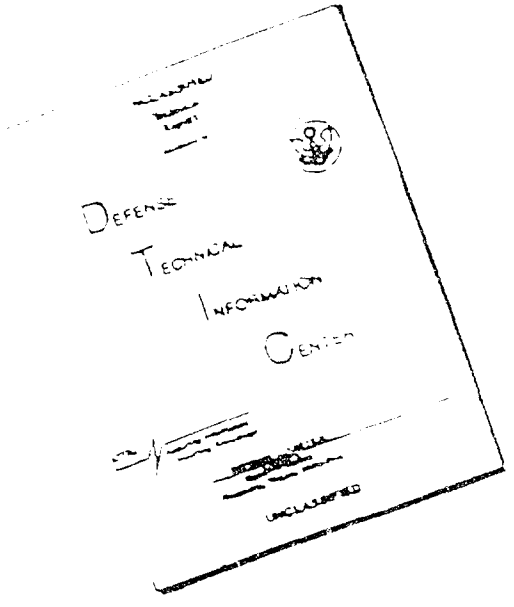
DETERMINATION OF PHYSICAL DATA OF THE HEAD I. CENTER OF GRAVITY AND MOMENTS OF INERTIA OF HUMAN HEADS

by

G. Beier, M. Schuck, E. Schuller, and W. Spann

Institut für Gerichtsmedizin der Universität München
D-8000 München, BRD

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

OFFICE OF NAVAL RESEARCH
Contract N 000 14-75-c-0486

SCIENTIFIC REPORT

DETERMINATION OF PHYSICAL DATA OF THE HEAD

I. CENTER OF GRAVITY AND MOMENTS OF INERTIA OF HUMAN HEADS

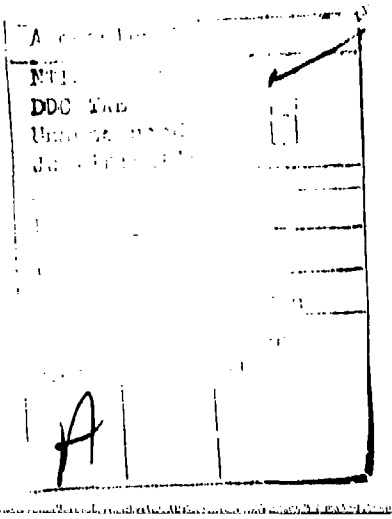
by

G. Beier, M. Schuck, E. Schuller, and W. Spann

Institut für Rechtsmedizin der Universität München
D-8000 München, BRD

Institute of Forensic Medicine
University of Munich
D-8000 Munich, West Germany

1 April 1979



SUMMARY

A study was conducted on fresh, unpreserved human heads of 19 male and 2 female cadavers to determine the three-dimensional location of the center of gravity and the moments of inertia about any axis related to an anatomically based coordinate system. Following the procedure of Becker (Ref. (3)) the heads were fixed for measurements within a tetrahedral frame which allows the determination of the center of gravity from the loads on its edge midpoints and the calculation of the inertial properties from the rotational oscillations of the trifilar suspended frame. For X-ray anthropometry radiographs were taken in three positions.

In the sample the ages at death range from 19 to 64 years, the body lengths from 156 to 185 cm, and the body weights from 53 to 95 Kg. The weights of the dissected heads range from 3.656 to 5.257 Kg. The center of gravity is located almost exactly in the mid-sagittal plane (± 0.3 cm), 2.2 to 4.3 cm above the Frankfort plane, and 0.2 to 1.3 cm in front of an axis connecting the external auditory meati. The inertial ellipsoid is degenerated to a rotational ellipsoid with the axis pointing to the forehead under an angle of 45 to 69 degree to the Frankfort plane. The principal moments about this axis range from 110 to 198 Kg·cm², the others from 136 to 274 and 167 to 298 resp.

TABLE OF CONTENTS

Determination of Physical Data of the Head:

Center of Gravity and Moments of Inertia of Human Heads

I INTRODUCTION

To apply the effects of experimentally produced impact accelerations utilizing human volunteers to the complete variety of the human being with respect to size, weight attitude etc. as well as to extrapolate the results up to and even beyond human tolerance, these data have to be acquired on a broad scale and under utmost "living" conditions; i. e. fresh cadaveric material, since whole body measurements on living human beings cannot provide these data, and the values known from measurements on preserved cadaveric specimens ask for validation to this respect. Certainly, the head and neck are among the most exposed elements to acceleration hazards. Therefore the physical data of the head were measured in order to determine

- -the three-dimensional location of the center of mass of the head related to an anatomically based coordinate reference system (ABCRS),
- -the moments of inertia of the head about any axis in this anatomically based coordinate reference system.

In addition three-dimensional X-ray anthropometry of the head was performed as reference for the applied ABCRS.

II METHODS AND DEFINITIONS

II-1 THE COORDINATE REFERENCE SYSTEM

The coordinate system to which all locations and directions of physical head data refer is the anatomically based coordinate reference system for the Head (ABCRS) as established by NAMRL Detachment, Michoud Station, New Orleans. It is based on four anatomical landmarks (Fig. II-1-1) and described by Thomas (1) as follows:

"The points (landmarks) are on the skin over the left and right infraorbital notches and at the superior edge of the left and right external auditory meati. The origin is at the midpoint of the left and right external auditory meatus markers. The +Z axis is from the origin in a cephalad direction perpendicular to the plane formed by the +X axis and the line between the auditory meatus markers. The +Y axis is from the origin toward the left ear perpendicular to the X-Z plane. The X-Z plane is considered the mid-sagittal plane".

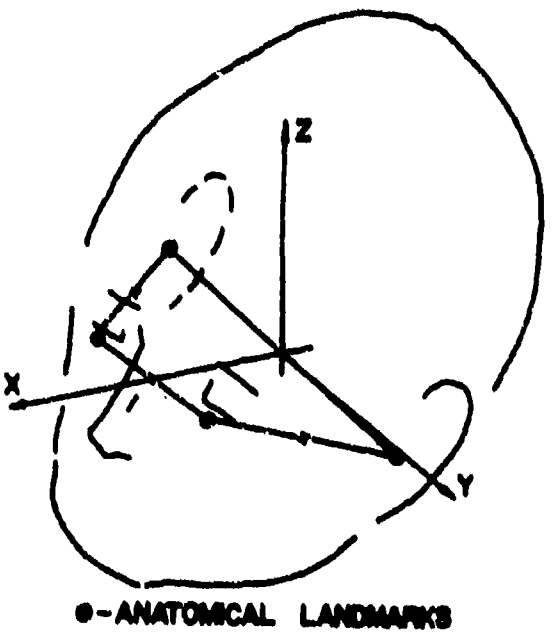


Fig. II-1-1: Anatomically based coordinate reference system (reproduced from Fig.1, Ref. (1))

II-2 PREPARATION OF THE SPECIMEN

II-2.1 STANDARD PLANE OF DIVISION

The standard plane of division of the head from the neck was that developed by Walker et al. (2) and defined as follows:
The neck is removed from the head by a cut originating at a point three-fourths of an inch below the external occipital protuberance and proceeding anteriorly and inferiorly to the atlanto-occipital joint. The cut proceeds to a point anterior to the prevertebral muscle mass. At this point, it intersects with a cut which begins at a point immediately inferior to the hyoid bone and extends cranially and posteriorly toward the cut described above (Fig. II-2.1-1).

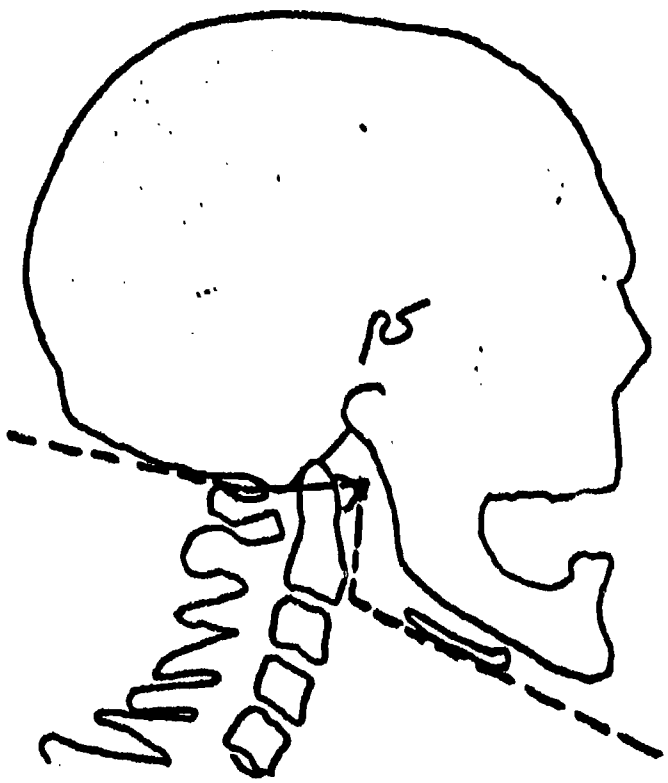


Fig. II-2.1-1: The plane of separation of the head from the neck indicated on a tracing of a lateral radiograph (reproduced from Fig. 2 Ref. (2))

II-2.2 METHOD OF DISSECTION AND PREPARATION

In order to maintain a standard distribution of fluids in the specimen, all specimens were prepared in the following manner: The cadaver is laid supine upon a table prior to dissection. A torniquet is applied carefully about the neck to close as much as possible the large vessels going to the head. The head is then allowed to hang down from the edge of the table. In this position the head is removed from the neck with a single cut through the region of the 2nd and the 3rd cervico-vertebral bodies. Keeping the separated specimen upside down to avoid fluid loss, the final dissection is performed according to the standard plane of division described in II-2.1.

Once the dissection is completed the dissection plane is sealed as follows: The large vessels are tied up. A hot flame is passed quickly over the area of dissection drying the surface and cauterizing the small vessels. The foramen magnum is plugged with a small piece of tissue paper. About 15 to 20 grams of hot paraffin is then spread over the surface and sealed with a final pass of the flame.

The advantage of this technique is that the weight losses during the course of the measurements are kept within 1 % of the total head weight.

The additional mass due to the paraffin, tissue and suture material is less than 25 grams.

For X-ray anthropometry the head is prepared by positioning lead markers in the right and left auditory meatuses and by inserting pins into the zygomatic bones.

The specimen is now ready for the measurements which proceed in the following order:

1) Head weight
2) Radiography
3) Center of Gravity
4) Moment of Inertia
5) Final Head Weight
6) Reference Measurements (empty jig)

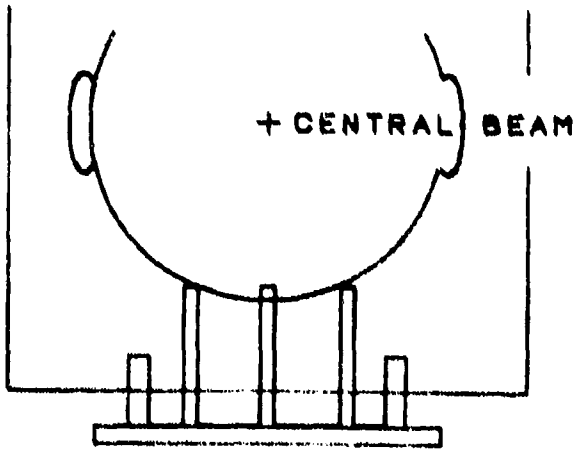


Fig. II-3-1: X-Ray set-up, frontal view

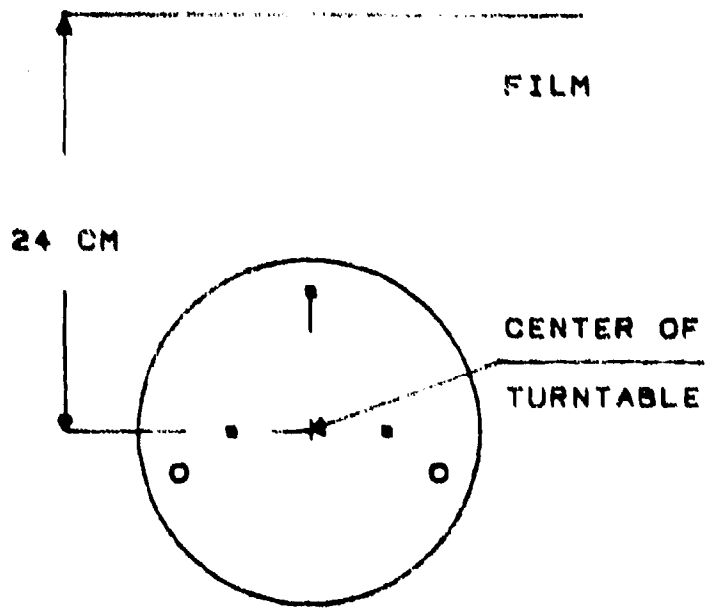


Fig. II-3-2: X-Ray set-up, top view

II-3 RADIOGRAPHY

For radiography the head rests upside down on three screws mounted on a turn-table as shown in Figs. III-3-1 and III-3-2. These screws, each 6 mm in diameter, are set in a triangular array at a center-to-center distance of 90 mm. Together with two more screws, 12 mm in diameter, 15 cm apart from each other and set relative to the triangular array as shown in Fig. III-3-2, this array serves as a reference for the radiographic evaluation.

The X-ray film is mounted 24 cm behind the center of the turn-table and about 200 cm from the focus of the X-ray tube. The central beam passes the center of the turn-table 9 cm above the heads of the 6 mm reference screws.

Of each specimen, prepared as outlined in II-2.2 and resting upside-down on the suspending set-up three radiographs are taken in the following positions:

0 degree	p-a	facing the film
45 degree		right side turned 45 degree towards the film
90 degree	lateral	right side turned towards the film

There are made no provisions or special adjustments to aligne the head on the turn-table to the anatomical coordinate system. Thus, the planes of the radiopgrahs do not coincide with the Y-Z plane and the X-Z plane resp. of the anatomical coordinate system. For each specimen this has to be determined separately from the bony structures, the position of the markers and the readings taken from the stereotaxic unit.

II-4 PHYSICAL MEASUREMENTS

The procedures for measuring the center of gravity and the moments of inertia are described in Reference (3). In these procedures, the head is placed in a stereotaxic jig as shown in Fig. II-4-1. This stereotaxic jig is designed to facilitate the center of gravity and moment of inertia measurements as well as to locate the head anatomical coordinates relatively to its own coordinate system.

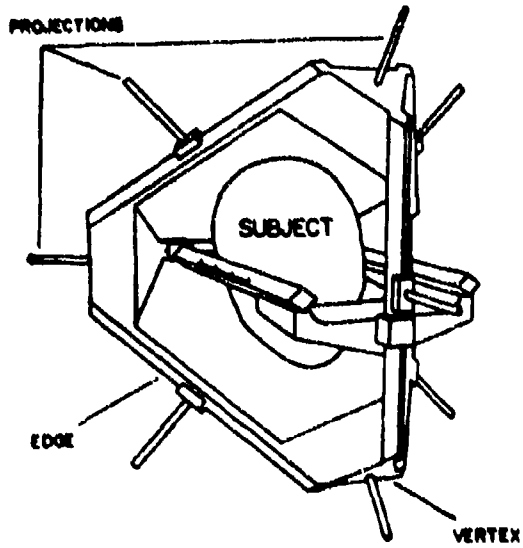


Fig. II-4-1: Stereotaxic unit and tetrahedral frame (Reproduced from Fig. 2 Ref. (3))

Two sets of measurements are made on the head-jig system. The first of these provides the information for the center of gravity of the total system. The second set then yields the system moments of inertia. The head is removed from the jig and the holding devices reset to their initial positions. The two sets of measurements for the head-jig system can then be compared to those of the empty jig to extract the center of gravity and the moments of inertia.

In addition to these measurements, the settings of the stereotaxic unit are recorded in order to locate the head anatomical coordinates relative to the jig hardware.

The data are then forwarded to the NAMRL Detachment, Michoud Station, New Orleans, for data reduction.

II-4.1 CENTER OF GRAVITY

The center of gravity measurements are essentially the same as those in Reference (3). The jig is positioned to rest on three of its edge-midpoint projections and the load on each projection is measured using a load cell. Since the jig can be supported on each of four different sets of these projections, a total of twelve measurements is obtained. The use of the load cell yields measurements accurately to within $\pm$ .005 LBS ($\pm$ 2.3 g) and is recommended in Reference (3) over the balance employed there.

II-4.2 MOMENTS OF INERTIA

For the determination of the inertial properties the jig is suspended from three wires in the manner of a trifilar pendulum. There are ten different orientations in which the jig may be suspended, four involving suspension by three of the vertexes and six more involving two vertexes and one edge-midpoint projection.

A light beam reflects from a mirror positioned on the jig in such a manner that slight rotational oscillations of the pendulum sweep the beam edge back and forth across a light sensitive device. This light sensitive device is coupled to an electric counter which measures the time for one hundred oscillations with an accuracy of one millisecond. The measurement is made twice for each of the ten orientations, and three times, if the difference between the first two readings exceeds one hundred milliseconds.

The suspension of the jig from the wires differs slightly from the technique described in Reference (3),since a cup and cone device was provided which permits much closer control of pendulum geometry.

III MATERIAL

Fresh, unpreserved human heads of 19 male and 2 female cadavers have been investigated. Serial number, registration number, age at death, body length and weight, cause of death and time elapsed between death and measurements are recorded for all specimens in Tab. III-0-1.

Distributions of age, body length and body weight are shown in Figs. III-0-1 to III-0-3. The ages at death range from 19 to 64 years with a mean value of 42.4 years and a median of 42 years. The body lengthes range from 156 to 185 cm with a mean value of 173 cm and a median of 175 cm. The body weights range from 53 to 95 Kg with a mean value of 74 Kg and a median of 73 Kg.

These specimens were selected from cadavers, delivered to the Institute of Forensic Medicine (University of Munich) during the period of 1975 to 1977. Attention was paid that the selected cadavers did not show any evidence of extensive blood loss, head injuries, bodily abnormalities, wasting desease or significant alterations due to immersion in water where it applies.

Tab. III-0-1

Ser. No.	Reg. No.	Age at death (years)	Body length (cm)	Body weight (Kg)	Cause of death	Measurement p.m.
1	1023/75	21	173	59	Undetermined	1d
2	1059/75	41	187	88	Coronary trombos.	44h
3	50/76	48	175	66	Traum.rupt. heart	86h
4	60/76	54	160	53	Coronary trombos.	43h
5	107/76	51	156	69	Traum.rupt. aorta	3d
6	233/76	40	175	61	Undetermined	2d
7 ♀	314/76	43	165	82	Drug overdose	5d
8	455/76	59	179	81	Carbonmonoxide	3d
9	665/76	-	179	66	Drowning	-
10 ♀	712/76	51	160	68	Drug overdose	3d
11	753/76	43	169	85	Myocardial infarc.	2d
12	833/76	50	178	99	Carbonmonoxide	-
13	245/77	52	180	79	Myocardial infarc.	3d
14	392/77	19	181	70	Drug overdose	4d
15	406/77	64	172	72	Carbonmonoxide	38h
16	448/77	36	177	95	Drug overdose	5d
17	564/77	39	185	73	Drowning	12h
18	662/77	35	172	65	Drowning	2d
19	667/77	28	177	85	Drowning	2d
20	791/77	28	176	77	Drowning	3d
21	820/77	41	172	76	Drug overdose	2d

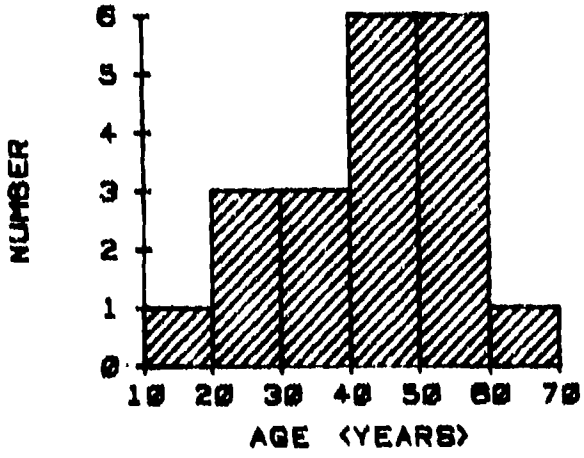


Fig. III-0-1: Distribution of age at death

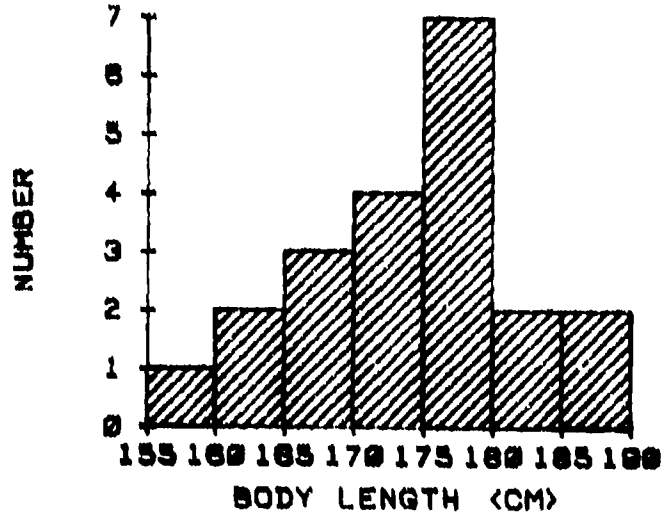


Fig. III-0-2: Distribution of body length

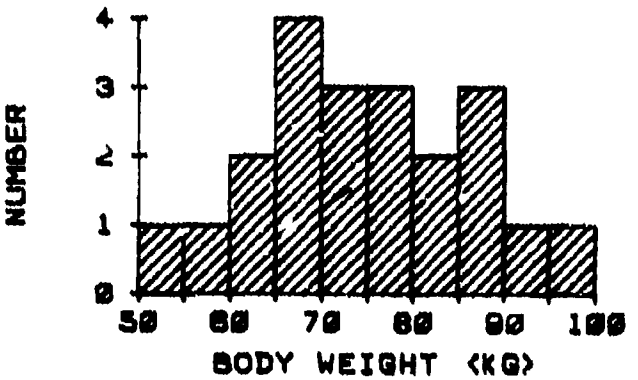


Fig. III-D-3: Distribution of body weight

The dissection and measurements were done at room temperature of 20 to 22 degree centigrade. Until these procedures could be performed the cadavers were stored at 4 to 6 degree centigrade. Maximum time elapsed between death and measurements was 5 days. Prior investigation has shown that there is no significant change in brain weight of fresh cadavers kept at 4 to 6 degree centigrade within at least the first one hundred hours after death (4).

IV RESULTS

IV 1 X RAY ANTHROPOMETRY

As an example prints of the whole set of radiographs (at 0, 45, and 90 degrees) of specimen No. 6 are reproduced in Fig. IV 1-1. The radiographs contain all information necessary for X-ray anthropometry to be performed in future studies. In Figs. IV 1-2 to IV 1-4 prints of the a-p and lateral radiographs are reproduced of the other specimens as far as available. Even though details are not discernible on these 1:4 scale prints, the general shape is revealed as a necessary reference for the interpretation of the physical data.

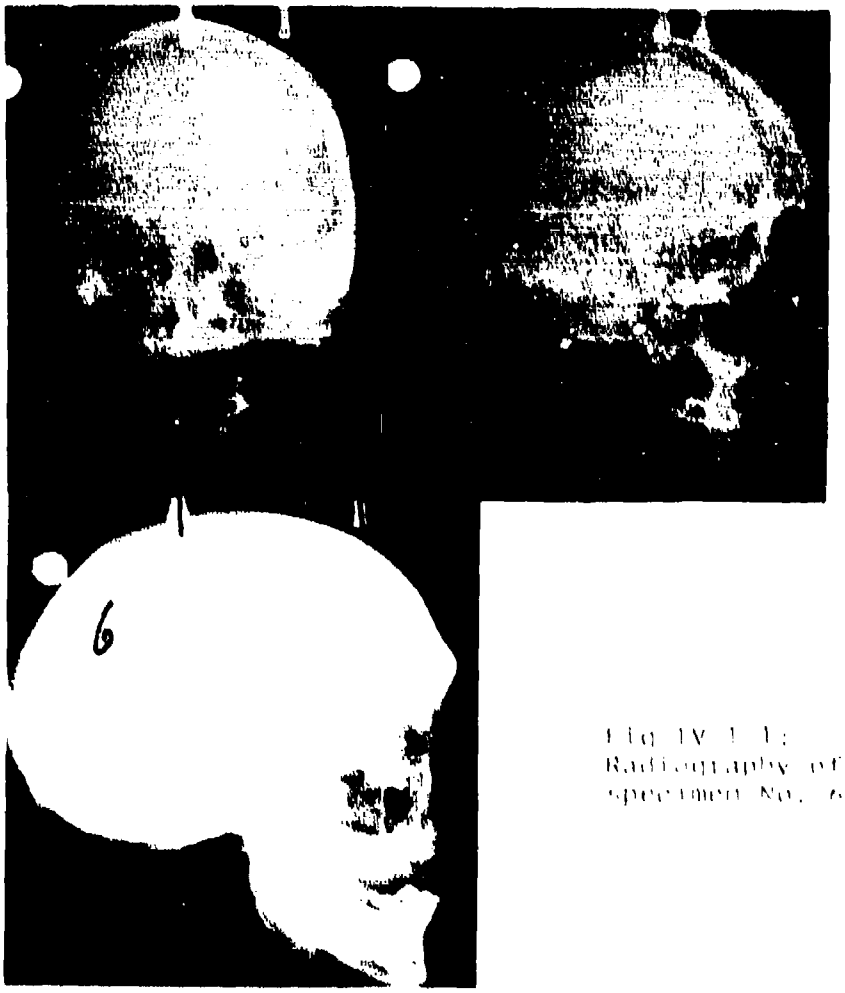


Fig IV 1-1:
Radiography of specimen No. 6

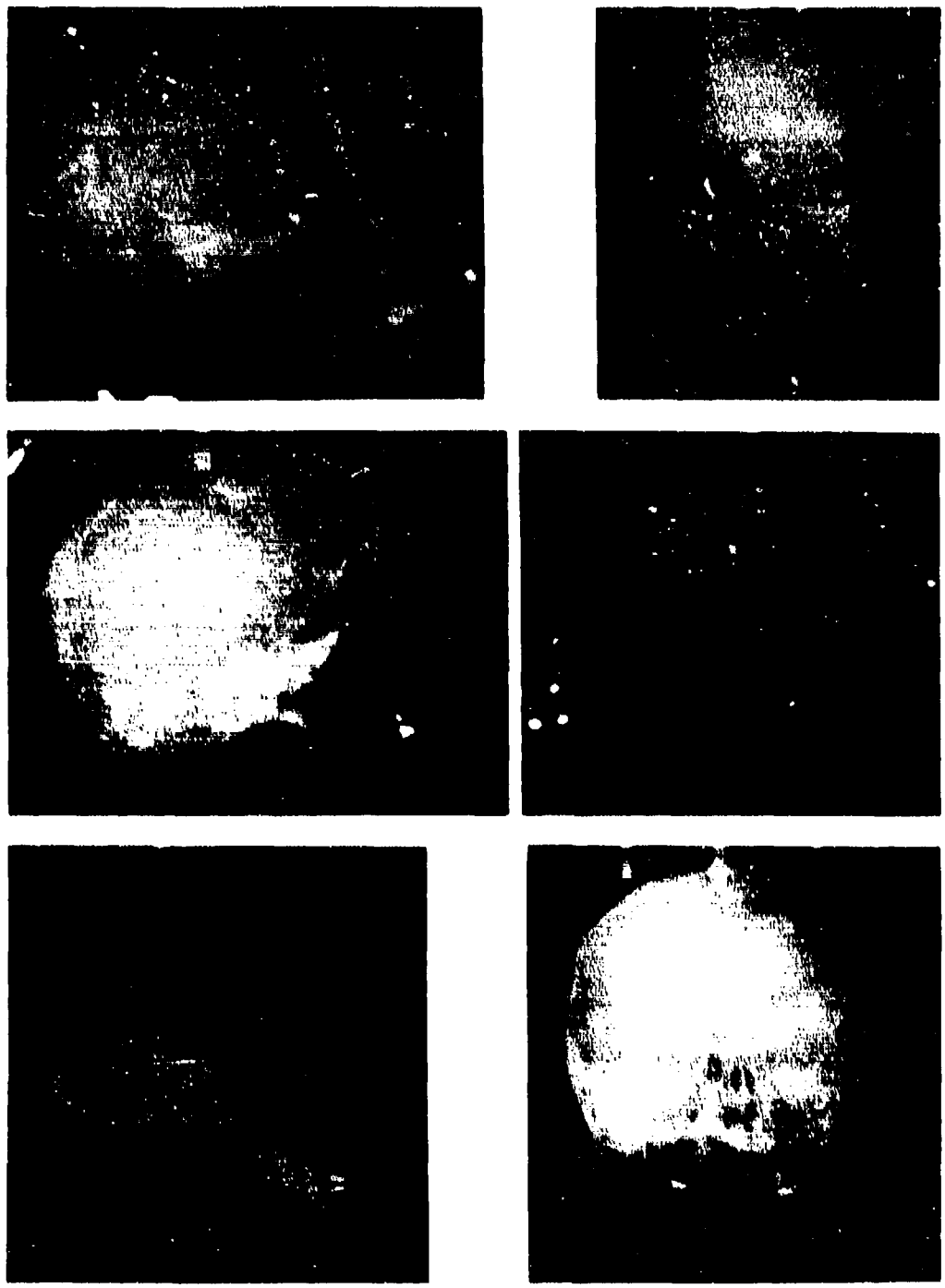


Fig. IV-2-2: Radiographs of specimens
No. 3, 4, and 5

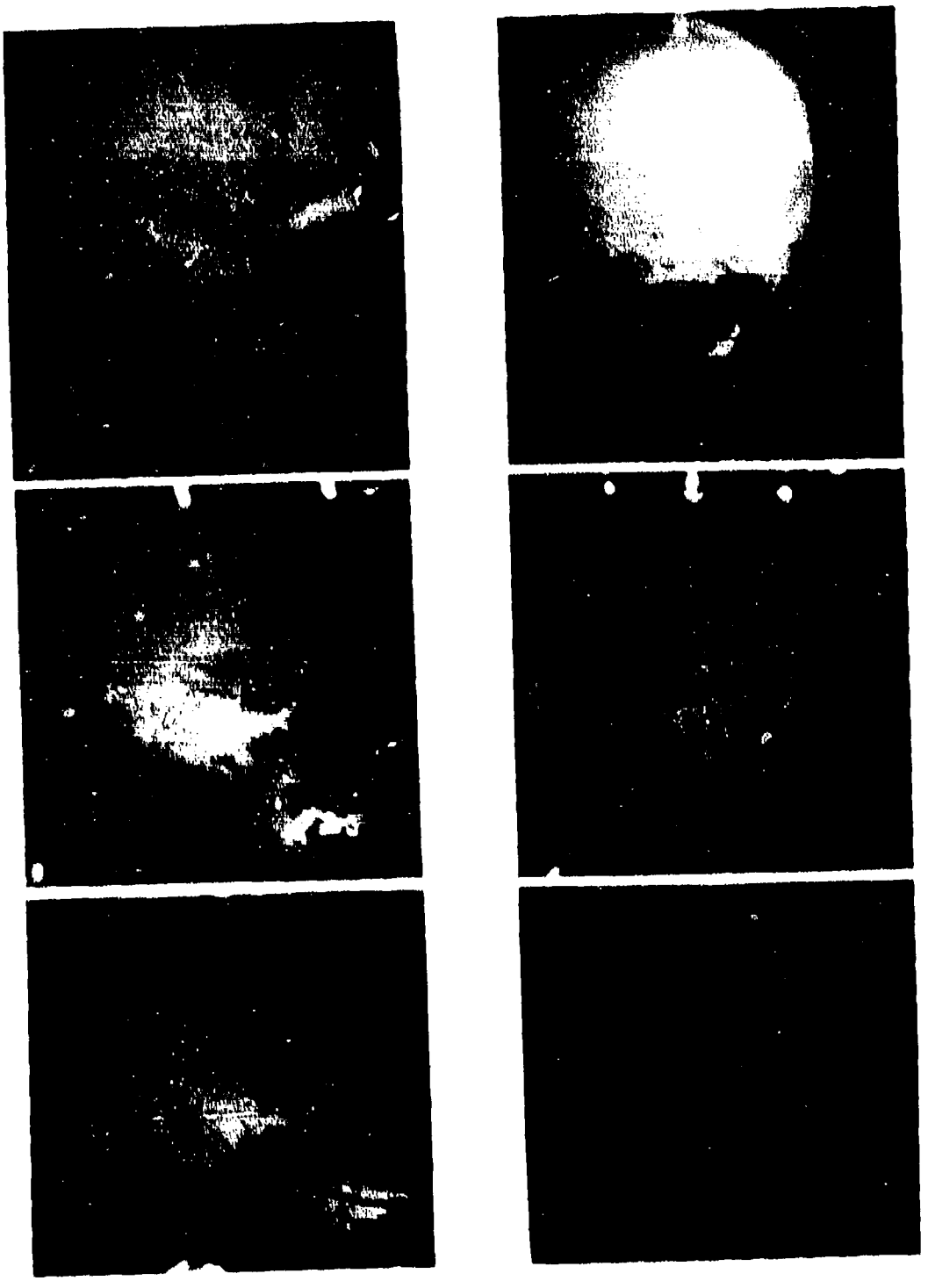


Fig. IV-1-3: Radiographs of specimens No. 7, 8, and 9

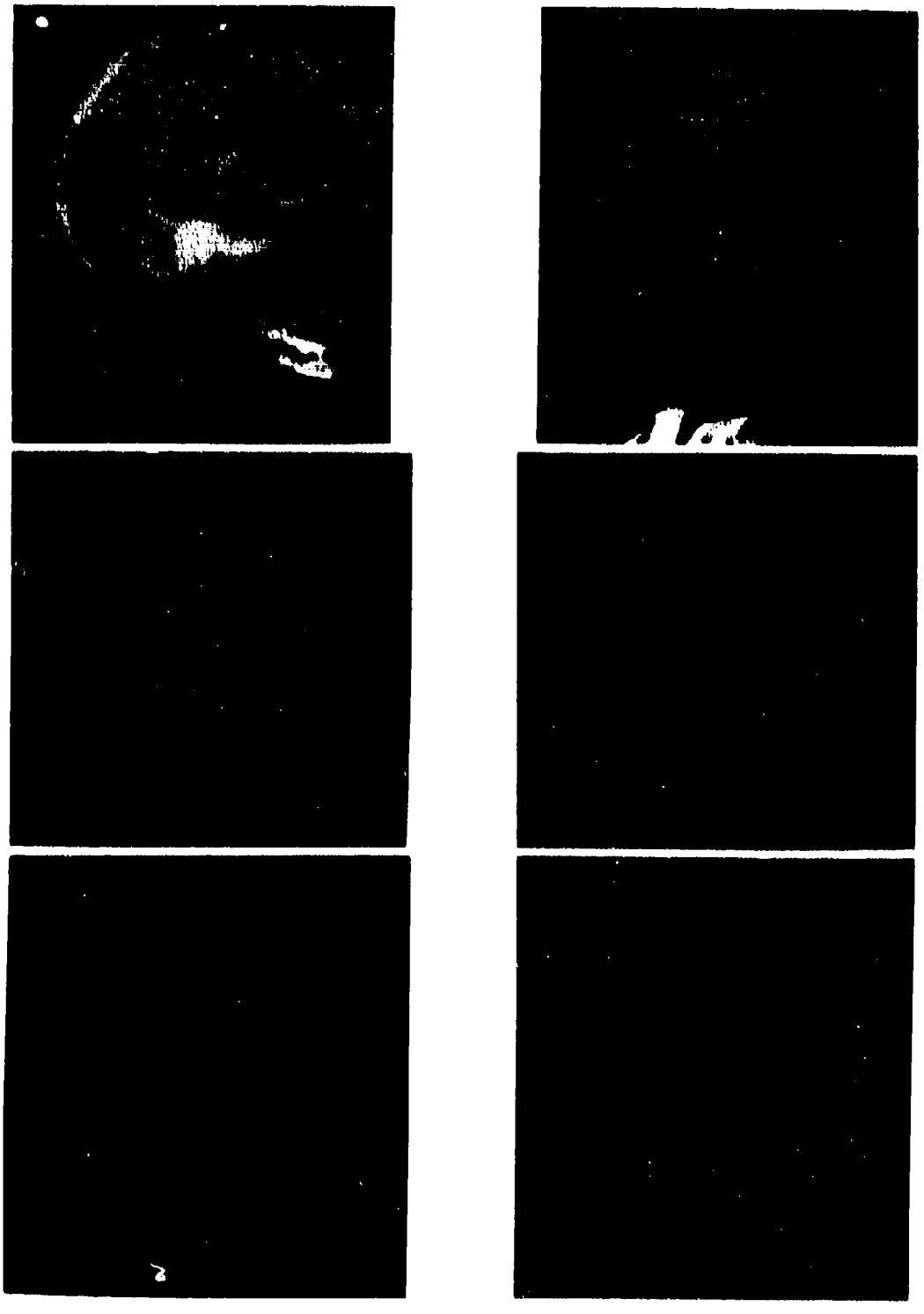


Fig. IV-1-4: Radiographs of specimens No. 10, 11, and 12

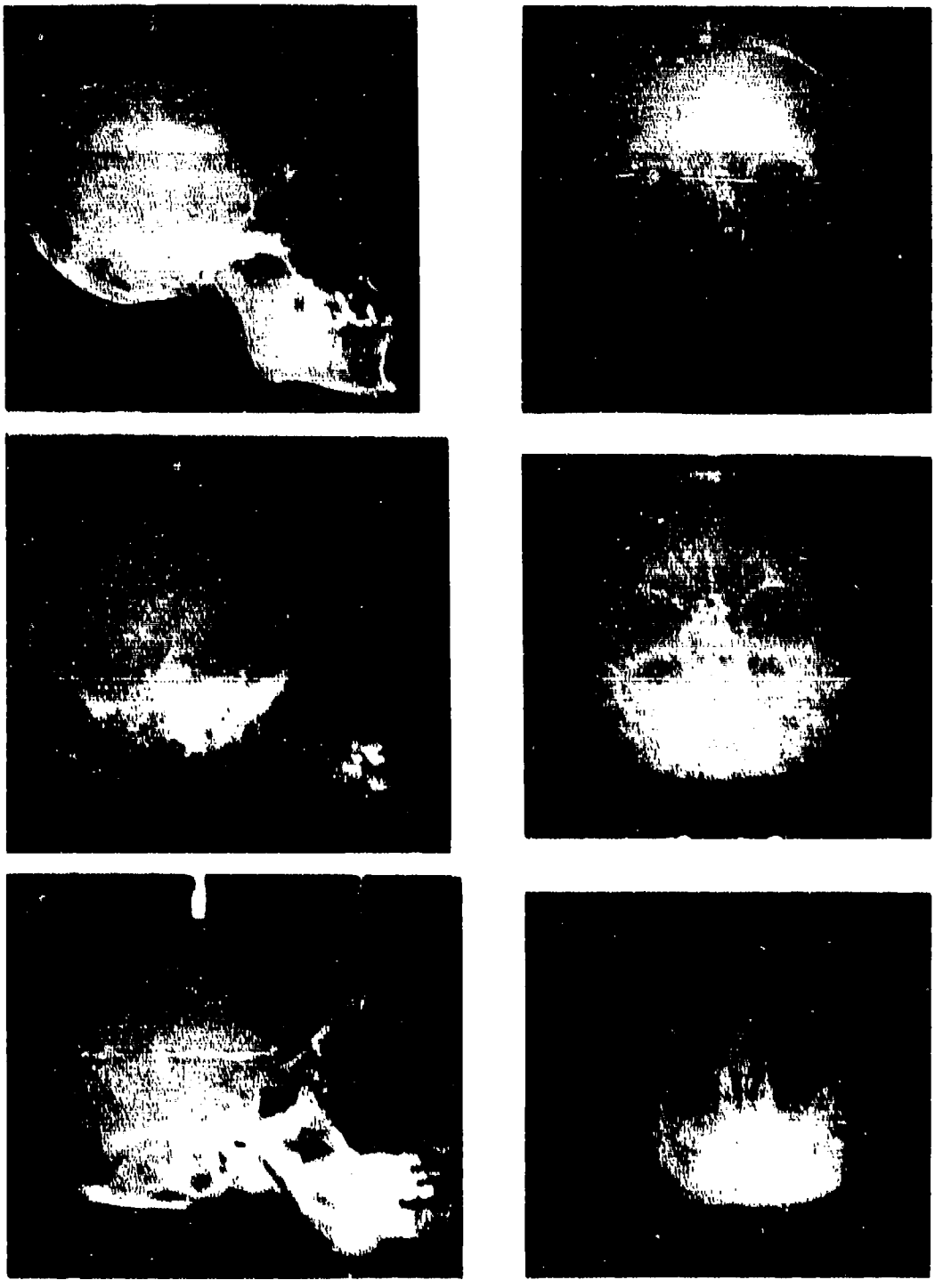


Fig. IV 1-5: Radiographs of specimens No. 13, 16, and 17

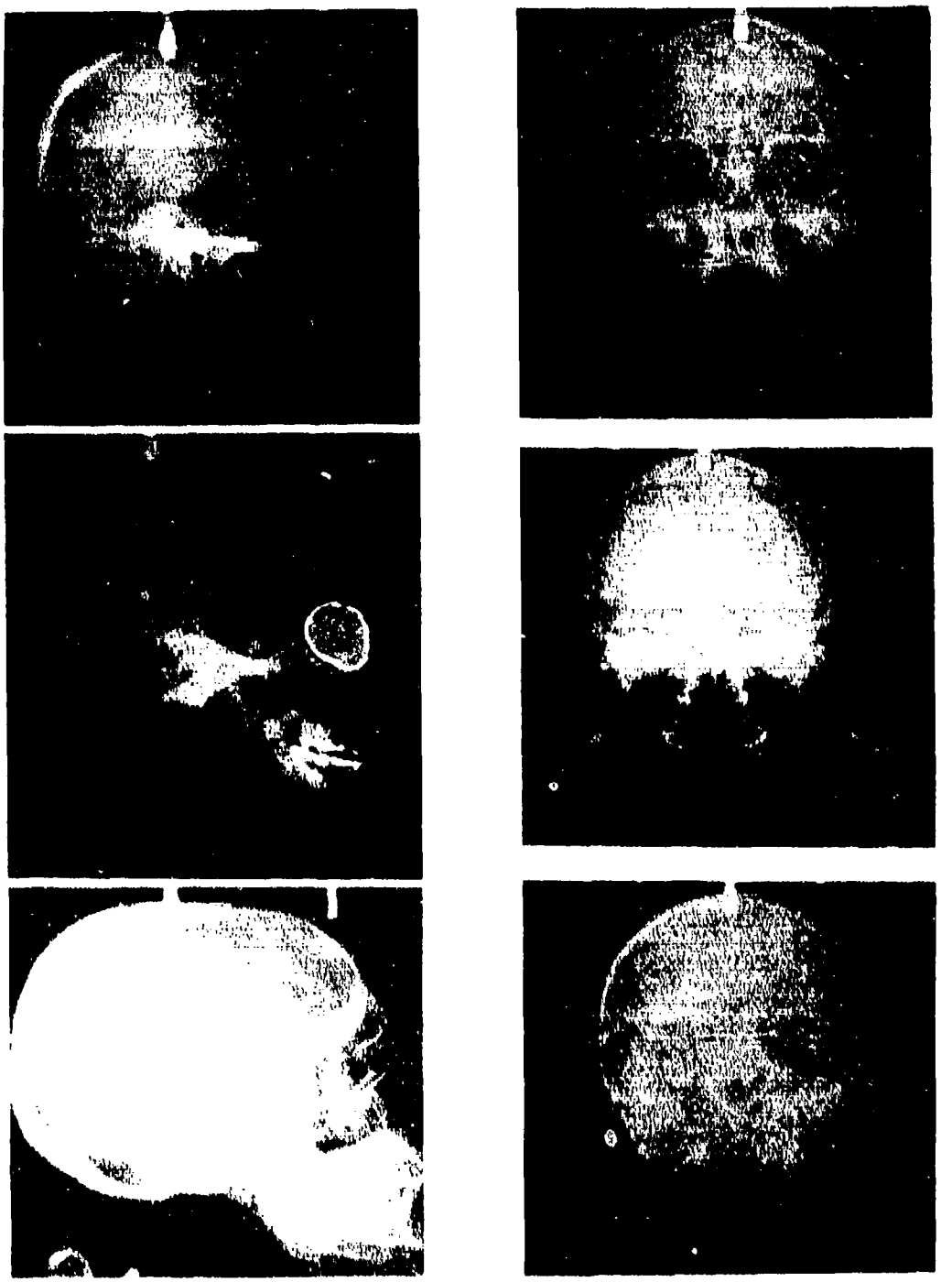


Fig. IV-1-6: Radiographs of specimens No. 18, 19, and 20

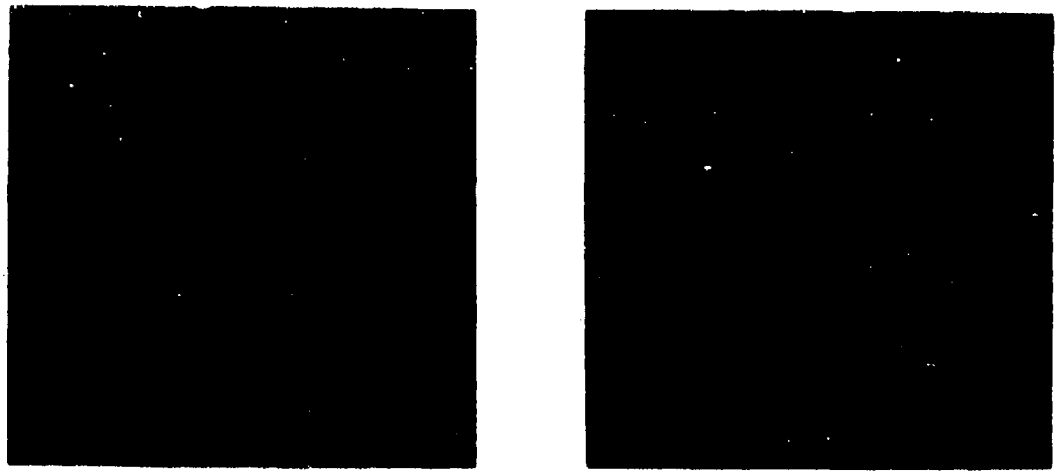


Fig. IV-1-7: Radiographs of specimen No. 21

IV-2 HEAD WEIGHTS

The head weight and the position of the center of gravity in the anatomically based coordinates are recorded along with body length and weight for each of the subjects in Tab. IV-2-1. The head weights listed are those taken before the measurements.

Tab. IV-2-1

Ser. No.	Body Length (cm)	Body Weight (Kg)	Head Weight (g)	Weight Loss (g)
1	173	59	4207	115
2	187	88	4120	31
3	175	66	3949	18
4	160	53	4028	5
5	156	69	4025	15
6	175	61	4190	32
7	165	82	4544	5
8	179	81	4652	21
9	179	66	4319	37
10	160	68	3705	18
11	169	85	4350	19
12	178	99	4335	7
13	180	79	4627	13
14	181	70	4627	46
15	172	72	4251	15
16	177	95	5257	10
17	185	73	4269	5
18	172	65	3676	9
19	177	85	3989	28
20	176	77	4142	25
21	172	76	5069	5

The loss shown is the difference between these weights and those taken after completion of the measurements. Since the sealing process described in II-2.2 was developed after the procedures were applied to the first specimen, the weight loss for this head is 2.7 % of the total head weight. The weight losses encountered for each of the remaining twenty heads are all less than 1 % of the total head weight.

The head weights range from 3 676 to 5 257 g. The mean value is 4 305 g, the standard deviation is 402 g. Their distribution is shown in Fig. IV-2-1. The distribution of the sample investigated by Walker et al. (2) is shown in Fig. IV-2-2. The means and standard deviations of both samples are compared in Tab. IV-2-2. Applying the T-test, no significant difference is found between these two samples. Direct comparison with the data of other investigators (5,6,7,8) is not possible due to differences in the plane of division.

Tab. IV-2-2

Source	Mean head weight (g)	Standard Deviation
Walker et al. (?)	4 376	591
Munich	4 305	402

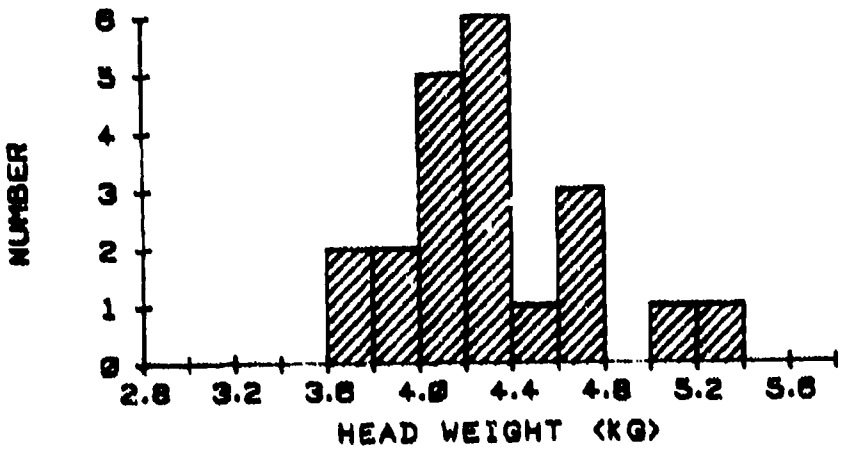


Fig. IV-2-1: Distribution of head weights (Munich)

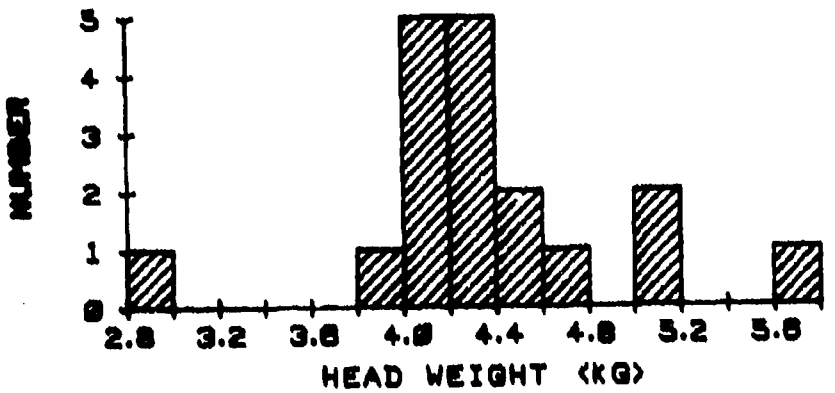


Fig. IV-2-2: Distribution of head weights (Walker et al. (2))

IV-3 CENTER OF GRAVITY

The center of gravity in the anatomically based coordinate reference system is recorded along with serial number, body length, body weight and head weight in Tab. IV-3-1.

The distributions of the X, Y and Z coordinates are shown in the histograms of Figs. IV-3-1 to Fig. IV-3-3. The values range

for the X-coordinate from 0.2 to 1.3 cm
for the Y-coordinate up to $\pm$.3 cm
for the Z-coordinate from 2.2 to $\overline{4}$.3 cm.

Tab. IV-3-1

Ser. No.	Body Length (cm)	Body Weight (Kg)	Head Weight (g)	Center of Gravity X	Y (cm)	Z
1	173	59	4207	0.72	-0.17	3.25
2	187	88	4120	1.37	-0.05	2.18
3	175	66	3949	1.05	-0.11	3.31
4	160	53	4028	0.85	-0.12	3.35
5	156	69	4025	0.88	-0.05	2.85
6	175	61	4190	1.02	-0.14	3.11
7	165	82	4544	0.28	0.05	2.96
8	179	81	4652	0.69	-0.19	4.24
9	179	66	4319	0.68	0.00	4.20
10	160	68	3705	0.66	-0.17	2.87
11	169	85	4350	0.63	0.34	2.70
12	178	99	4335	0.40	-0.15	2.67
13	180	79	4749	1.10	0.00	4.13
14	181	70	4627	0.90	0.03	3.31
15	172	72	4251	0.72	0.07	2.98
16	177	95	5257	1.13	-0.15	2.94
17	185	73	4269	0.62	-0.09	3.17
18	172	65	3676	0.97	-0.26	2.67
19	177	85	3938	1.14	-0.10	2.53
20	176	77	4142	0.79	-0.04	2.67
21	172	76	5069	0.82	0.15	3.72

The data show that the center of gravity is located almost exactly in the X-Z plane of the anatomical coordinates which is the mid-sagittal plane of the head. The maximum deviation from this plane is less than 3 millimeters.

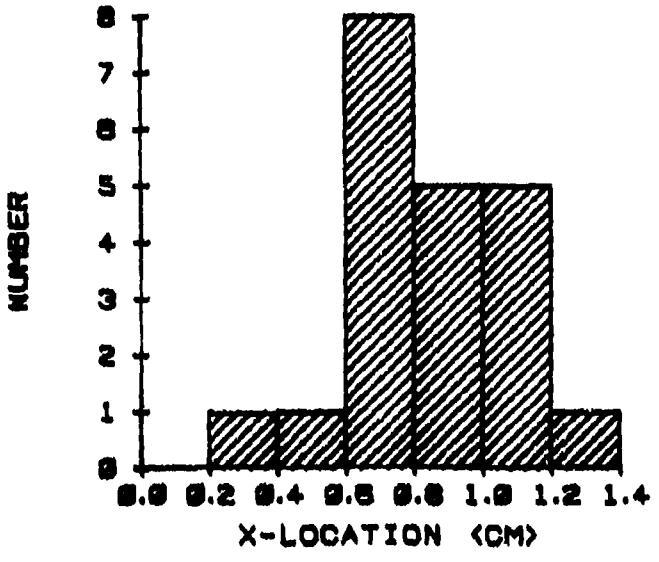


Fig.IV-3-1: Distribution of the X-coordinates of the center of gravity

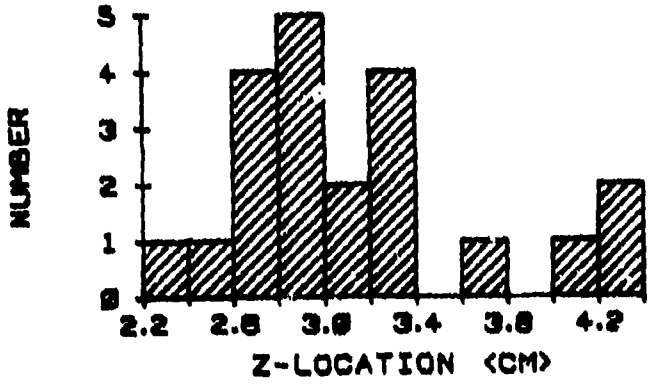


Fig. IV-3-2: Distribution of the Z-coordinates of the center of gravity

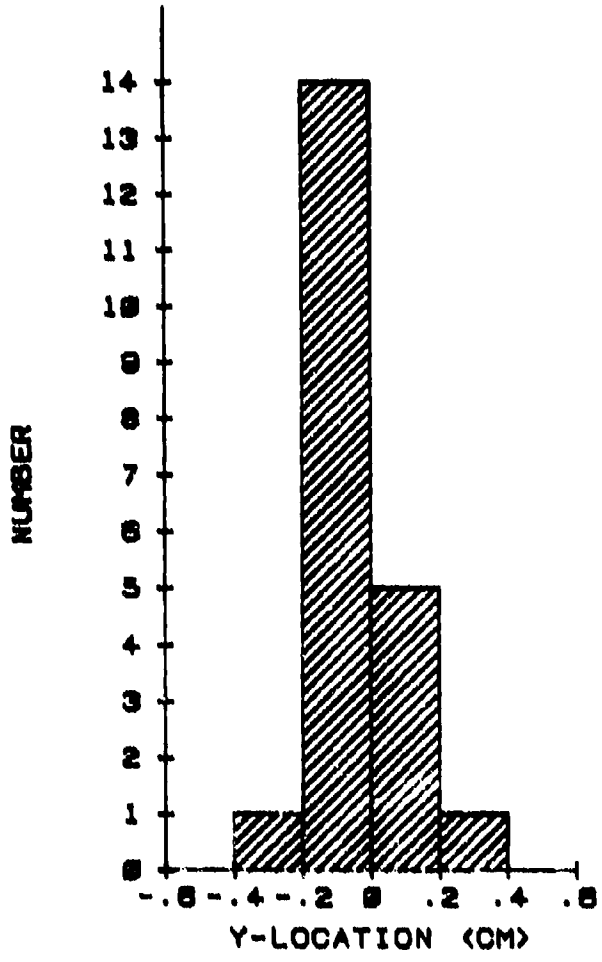


Fig. IV-3-3: Distribution of the Y-coordinates of the center of gravity

The locations of the centers of gravity within the X-Z plane are shown in Fig. IV-3-4. The means and standard deviations are given in Tab. IV-3-1. As a mean, the center of gravity of the head is located within the mid-sagittal plane, 0.8 cm in front of the auditory meatuses and 3.1 cm above the Frankfort Plane. (Fig. IV-3-5)

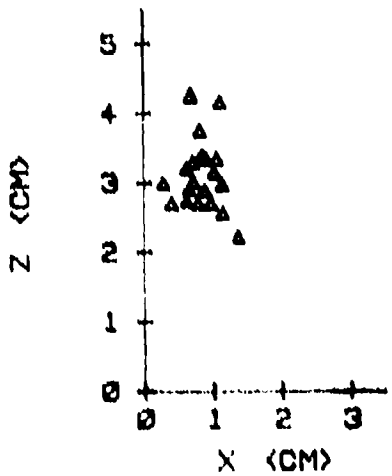


Fig. IV-3-4:
Location of the center of gravity within the X-Z-plane

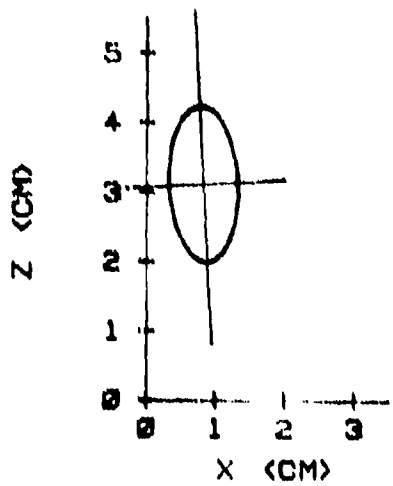


Fig. IV-3-5:
Location of the mean center of gravity within the X-Z-plane and 2s-ellipse of standard deviation

The matrix of the Eigenvectors - which gives the orientation of the ellipsoid of variance - may be considered as a unit matrix and the distribution of the variance on each of the three axes assumed to be independent. Thus the principal values give the standard deviation of each of the three axes. In Fig. IV-3-5 the distribution within the X-Z plane is revealed by the 2s-ellipse about the mean center of gravity.

For comparison, the mean and standard deviation calculated from the data published by Walker et al. (2) are cumulated in Tab. IV-3.3. Applying the T-test a significant difference ($p = 0.01$ and 0.05 resp.) exists between the means of Walker's sample and that of this study. Compared to the embalmed specimens the mean center of gravity of fresh human heads is located about 1 cm retro-cranial, i. e. towards the center of the brain. Besides possible systematical differences due to different experimental procedures the reason may be a weight-loss of the soft tissue during fixation or fluid loss during the measurements of the embalmed specimens.

Tab. IV-3-2
Analysis of the center of gravity data
(This analysis was done by E. Becker, NAMRL Detachment, New Orleans, LA, USA)

	Mean	Standard Deviation	Eigenvektors		
X	.83	.25	.990	-.136	.054
Y	-.05	.13	.137	.990	-.004
Z	3.12	.56	-.053	.012	.999

Tab. IV-3-3
Center of gravity from the photo-measurements of Walker et al. Ref. (2)

	Mean	Standard Deviation
X	1.42	0.76
Y	not determined	
Z	2.41	1.03

No. of specimens: 17

IV-4 MOMENTS OF INERTIA

IV-4-1 PRINCIPAL AXES

For each specimen the tensor of the principal axes (X', Y', Z') of the moments of inertia are recorded in Tab. IV-4-1. These tensors yield orientations relative to the planes of the anatomical coordinate system.

Tab.IV-4-1: Tensor of the principal axes of the moments of inertia

Ser. No.	X	Y	Z	
1	.881	-.313	.353	X'
	.277	.949	.148	Y'
	-.382	-.032	.992	Z'
2	.693	-.502	.516	X'
	.424	.863	.270	Y'
	-.582	.031	.812	Z'
3	.731	.383	.564	X'
	-.305	.923	-.232	Y'
	-.610	-.002	.792	Z'
4	.809	.090	.580	X'
	-.163	.983	.075	Y'
	-.564	-.156	.810	Z'
5	.737	.263	.621	X'
	-.184	.964	-.189	Y'
	-.649	.025	.759	Z'
6	.765	.250	.593	X'
	-.205	.968	-.142	Y'
	-.610	.012	.792	Z'
7	.847	-.033	.529	X'
	.047	.998	-.019	Y'
	-.528	.035	.847	Z'
8	.861	-.310	.401	X'
	.299	.949	.092	Y'
	-.410	.040	.911	Z'
9	.514	-.551	.656	X'
	.579	.787	.208	Y'
	-.631	.273	.725	Z'
10	.763	.298	.572	X'
	-.253	.954	-.159	Y'
	-.593	-.023	.804	Z'

Tab. IV-4-1: Tensor of the principal axes of the moments of inertia (continued)

Ser. No.	X	Y	Z	
11	.536	-.744	.397	X'
	.659	.664	.352	Y'
	-.526	.072	.846	Z'
12	.801	.160	.576	X'
	-.098	.985	-.136	Y'
	-.590	.052	.805	Z'
13	.905	-.114	.409	X'
	.118	.992	.016	Y'
	-.408	.033	.912	Z'
14	.835	-.137	.532	X'
	.097	.989	.102	Y'
	-.541	-.034	.840	Z'
15	.576	.571	.583	X'
	-.415	.820	-.392	Y'
	-.703	-.016	.710	Z'
16	.756	-.343	.556	X'
	.305	.938	.162	Y'
	-.577	.046	.814	Z'
17	.722	-.082	.680	X'
	-.080	.976	-.201	Y'
	.686	.201	.698	Z'
18	.692	-.574	.437	X'
	.467	.818	.304	Y'
	-.532	.002	.846	Z'
19	.912	.035	.407	X'
	-.044	.998	.012	Y'
	-.406	-.029	.913	Z'
20	.746	.045	.664	X'
	.020	.995	-.090	Y'
	-.665	.081	.741	Z'
21	.850	-.286	.440	X'
	.214	.954	.206	Y'
	-.479	-.081	.873	Z'

Tab. IV-4-2
Deviation of the principal axes (X' ,Y' ,Z')
of the moments of inertia (degrees)

Ser. No.	X' from X-Z plane	Y' from X-Z plane	Z' from Z-Y-plane	Z' from Z-X-plane
1	-19.5	73.7	-21.0	- 1.8
2	-35.9	63.8	-35.6	2.1
3	27.6	-71.7	-37.6	- 0.1
4	6.3	-80.5	-34.8	-10.9
5	19.6	-79.1	-40.5	1.8
6	18.0	-78.0	-37.6	0.8
7	- 2.2	87.3	-31.9	2.3
8	-19.8	72.5	-24.2	2.5
9	-46.9	53.6	-41.0	20.6
10	21.3	-75.1	-36.4	- 1.6
11	-54.2	45.2	-31.8	4.8
12	11.2	-84.3	-36.2	3.6
13	- 7.1	83.2	-24.1	2.0
14	- 9.3	84.3	-32.7	- 2.3
15	44.7	-63.1	-44.7	- 1.2
16	-24.4	71.9	-35.3	3.2
17	- 6.4	-85.3	-44.5	16.0
18	-39.6	59.2	-32.1	0.1
19	2.1	-87.4	-23.9	- 1.8
20	3.4	88.8	-41.9	6.2
21	-18.5	77.3	-28.7	- 5.3

In Tab. IV-4-2 the following orientations are listed:
The deviation of X' from the X-Z plane
= the projection of X' onto the Frankfort plane.
The deviation of Y' from the X-Z plane
= the projection of Y' onto the Frankfort plane.
The deviation of Z' from the Z-Y plane
= the projection of Z' onto the mid-sagittal plane.
The deviation of Z' from the Z-X plane
= the projection of Z' onto the latero-lateral plane.

The distribution of the Z' orientation with respect to the latero-lateral and the mid-sagittal plane are given in the histograms of Figs. IV-4-1 and IV-4-2 resp. and the diagrams of Figs. IV-4-3 and IV-4-4 resp.. The deviation from the Z-Y plane varies from -21 to -45 degrees with a mean of 34 degree.
The lateral variation of Z' may exceptionally amount to ± 20 degree, but is in 85 % of the specimens smaller than ± 10 degree. No side seems to be favored.

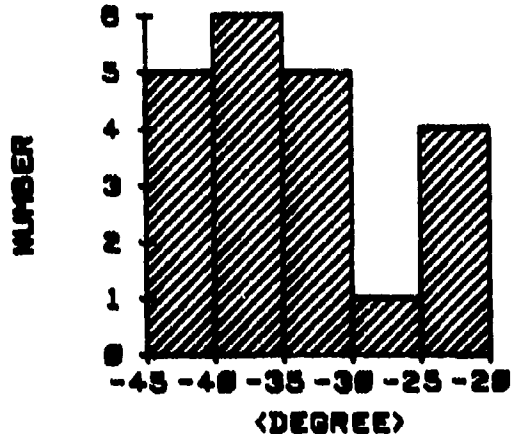


Fig. IV-4-1: Deviation of Z' from Z-Y-plane

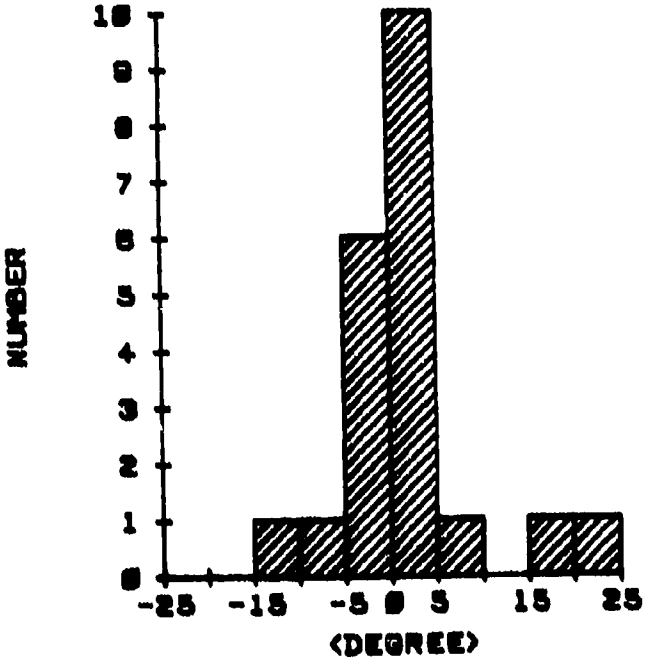


Fig. IV-4-2: Deviation of Z' from Z-X-plane

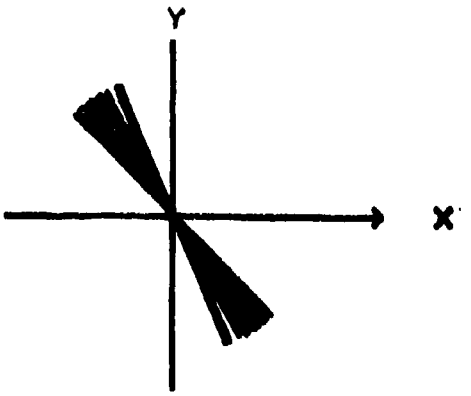


Fig. IV-4-3:
Projection of the principal axis Z' onto the mid-sagittal (X-Y) plane

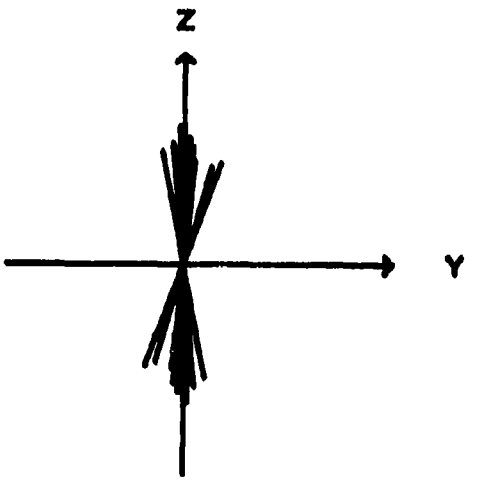


Fig. IV-4-4:
Projection of the principal axis Z' onto the latero-lateral (Y-Z) plane

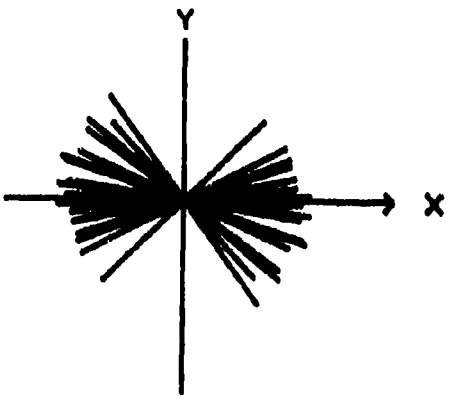


Fig. IV-4-5:
Projection of the principal axis X' onto the Frankfort plane

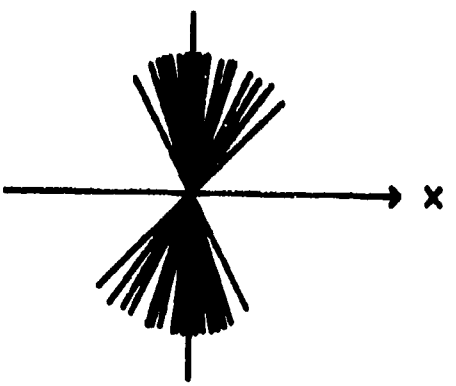


Fig. IV-4-6:
Projection of the principal axis Y' onto Frankfort plane

The distributions of the X' and Y' deviations from the mid-sagittal plane are shown in the diagrams of Figs. IV-4-5 and IV-4-6 and the histograms of Figs. IV-4-7 and IV-4-8 resp.. They reveal, that these principal moment orientations are almost indistinct with respect to the mid-sagittal plane. In the mean, therefore, the X'-Y'-cross-section of the principal inertia ellipsoid degenerates to a circle rendering calculation of the orientations meaningless.

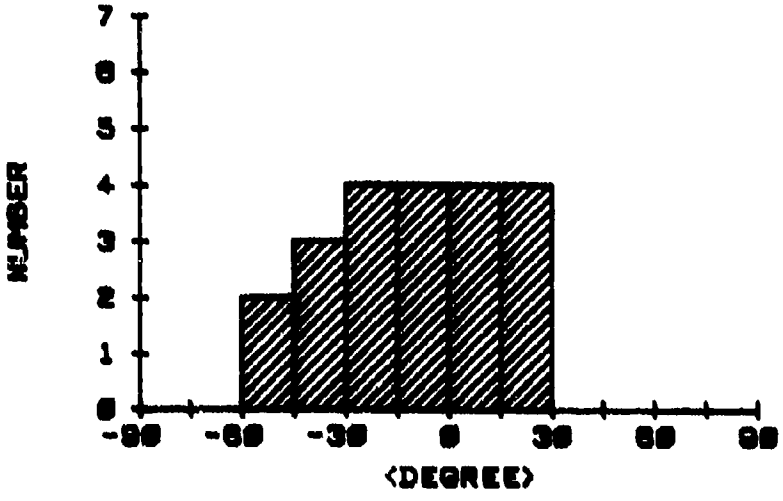


Fig. IV-4-7: Deviation of X' from mid-sagittal plane

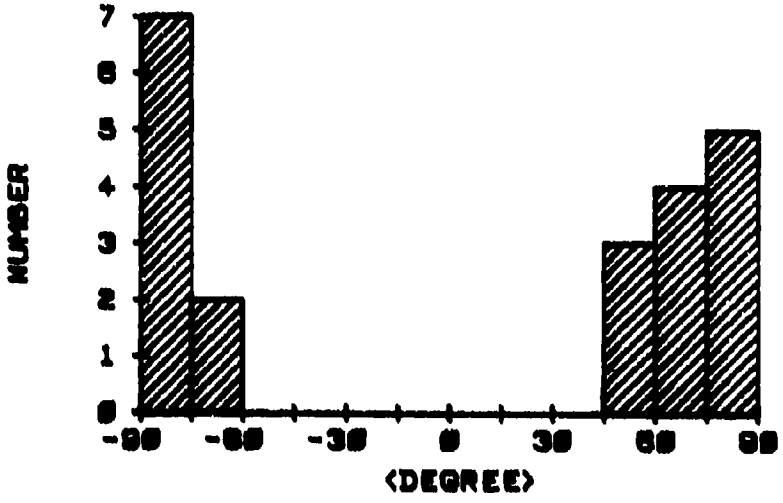


Fig. IV-4-8: Deviation of Y' from mid-sagittal plane

IV-4.2 PRINCIPAL MOMENTS

The principal moments are listed along with head weights in Tab. IV-4-3. Their distribution is shown in the histograms of Figs. IV-4-9 to IV-4-11. The principal moments vary

from 136 to 274 $Kg \cdot cm^2$ about the X' axis

from 167 to 298 $Kg \cdot cm^2$ about the Y' axis

from 110 to 198 $Kg \cdot cm^2$ about the Z' axis

Tab. IV-4-3: Principal moments of inertia

Ser. No.	Head Weight (g)	Principal moments of inertia X'	Y'	Z'
			($Kg \cdot cm^2$)	
1	4207	200	238	143
2	4120	204	213	134
3	3949	191	207	119
4	4028	188	202	129
5	4025	193	197	138
6	4190	204	214	147
7	4544	227	238	156
8	4652	228	264	180
9	4319	197	232	148
10	3705	157	159	116
11	4350	215	225	153
12	4335	213	221	143
13	4749	247	243	169
14	4627	236	258	156
15	4251	215	208	142
16	5257	274	298	194
17	4269	136	223	198
18	3676	154	167	110
19	3938	175	192	121
20	4142	201	207	131
21	5069	268	286	189

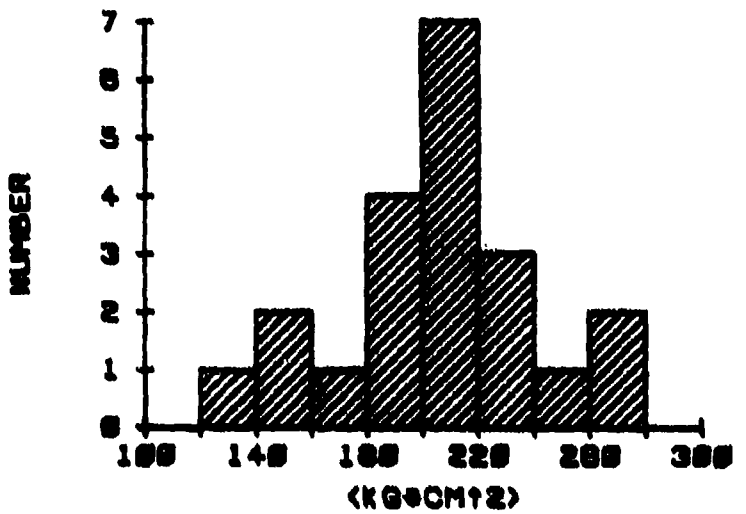


Fig. IV-4-9: Distribution of principal moments of inertia about the X' axis

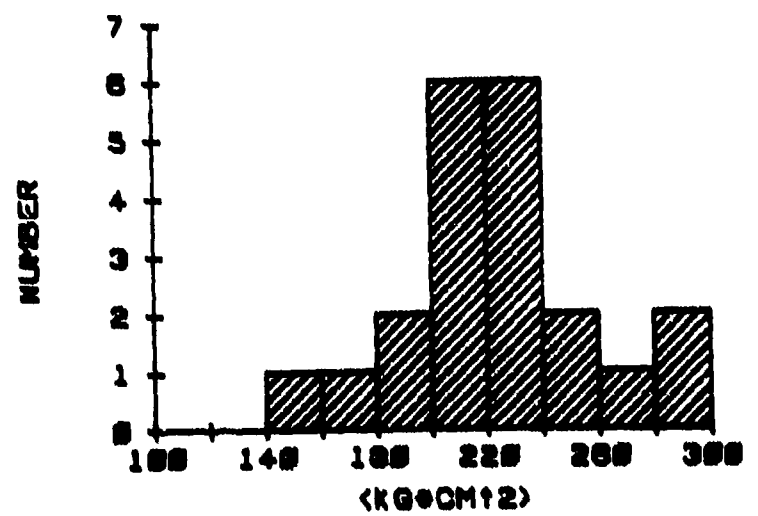


Fig. IV-4-10: Distribution of principal moments of inertia about the Y' axis

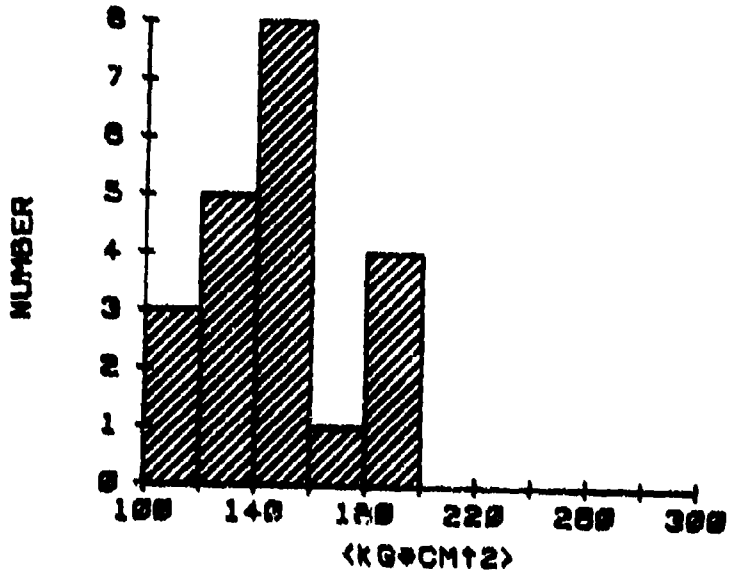


Fig. IV-4-11: Distribution of principal moments of inertia about the Z' axis

V REFERENCES

(1) THOMAS, D. J.: Specializised Anthropometry Requirements for Protective-Equipment Evaluation. AGARD Conf. Proc. No. 110, Glasgow, Scotland, 1972.

(2) WALKER, L. B., HARRIS, E. H. ,and PONTIUS, U. R.: Mass, Volume, Center of Mass and Mass Moment of Inertia of Head and Head and Neck of the Human Body. Final Report to ONR, March 15, 1973.

(3) BECKER, E. D.: Measurement of Mass Distribution Parameters of Anatomical Segments. Proc. of 16th Stapp Car Crash Conf., p. 160. New York: Society of Automotive Engineers, Inc., 1973.

(4) BEIER, G., EISENMENGER, W., SPANN, W., and STEINBERGER, E.: Beziehungen zwischen Hirndruck, Hirngewicht und Osmolarität. I. Günzburger Gespräch, Schattauer Verlag, 1976, p.11.

(5) BRAUNE, W. and FISCHER, O.: Über den Schwerpunkt des menschlichen Körpers mit Rücksicht auf die Ausrüstung des deutschen Infanteristen (The Center of Gravity of the Human Body as Related to the Equipment of the German Infantryman). Abh. d. math. phys. Classe d. k. Sächs. Ges. d. Wiss. 15 (1889), p. 561.

(6) DEMPSTER, W. T.: Space Requirements of the seated Operator. WADC-TR-159. Aeromedical Laboratory, Wrigth Air Development Center, Wrigth-Patterson Air Force Base, Ohio, 1955.

(7) CLAUSER, C. E., McCONVILLE, J. T., and YOUNG, J. W.: Weight, Volume, and Center of Mass of Segments of the Human Body. AMRL-TR-69-70. Aerospace Medical Research Laboratory, Wrigth-Patterson Air Force Base, Ohio, 1969

(8) LIU, Y. K., LABORDE, J. M., and VAN BUSKIRK, W. C.: Inertial Properties of a Segmented Cadaver Trunk: Their Implications in Acceleration Injuries. Aerospace Med. 42, (1971), p. 650.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 1
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER: (9)

4. TITLE (and Subtitle): (6) DETERMINATION OF PHYSICAL DATA OF THE HEAD; I. CENTER OF GRAVITY AND MOMENTS OF INERTIA OF HUMAN HEADS.

5. TYPE OF REPORT & PERIOD COVERED: Scientific Report, No. 1, 1 Feb 75 — 30 Sep 78
6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): (10) Gundolf Beier, Manfred Schuck, Erich Schuller and Wolfgang Spann
8. CONTRACT OR GRANT NUMBER(s): (15) N0001 4-75-C-0486

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Institut für Rechtsmedizin der Universität München, Frauenlobstr. 7 a
D-8000 Munich 2, West-Germany

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 414312

11. CONTROLLING OFFICE NAME AND ADDRESS:
Program Director Biophysics
Code 444, Office of Naval Research
Arlington, VA 22217

12. REPORT DATE: (11) 19 Apr 79
13. NUMBER OF PAGES: 25 (13) 41

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
Program Director Biophysics
Code 444, Office of Naval Research
Arlington, VA 22217

15. SECURITY CLASS. (of this report): unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: N.A.

16. DISTRIBUTION STATEMENT (of this Report):
unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
unlimited

18. SUPPLEMENTARY NOTES:
N.A.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
Anthropometry; Biomechanics
Human Engineering; Head - Mass, Center of gravity, Moments of Inertia; Human Body Models; Anatomy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):
A study was conducted on fresh, unpreserved human heads of 19 male und 2 female cadavers to determine the three-dimensional location of the center of gravity and the moments of inertia about any axis related to an anatomically based coordinate system.
The ages at death range from 19 to 64 years, the body lengths from 156 to 185 cm, and the body weights from 53 to 95 kg. The weights of the dissected heads range from 3,656 to 5,257 kg. The

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

411569

20. (Continued)
center of gravity is located almost exactly in the mid-sagittal plane (+ 0,3 cm), 2.2 to 4.3 cm above the Frankfort plane, and 0.2 to 1.3 cm in front of an axis connecting the external auditory meati. The inertial ellipsoid is degenerated to a rotational ellipsoid with the axis pointing to the forehead under an angle of 45 to 69 degree to the Frankfort plane. The principal moments about this axis range from 110 to 198 kg.cm^2, the others from 135 to 274 and 167 to 298 resp..

Munich Univ. (Germany, F.R.) Inst. für Rechtsmedizin

DISTRIBUTION LIST FOR TECHNICAL, ANNUAL AND FINAL REPORTS

Number of Copies	
(12)	Administrator, Defense Documentation Center Cameron Station Alexandria, Virginia 22314
(6)	Director, Naval Research Laboratory Attention: Technical Information Division Code 2627 Washington, D.C. 20375
(6)	Office of Naval Research Attention: Code 102IP (ONRL DOC) 800 N. Quincy Street Arlington, Virginia 22217
(3)	Office of Naval Research Biophysics Program Code 444 Arlington, Virginia 22217
(1)	Commanding Officer Naval Medical Research and Development Command National Naval Medical Center Bethesda, Maryland 20014
(1)	Chief, Bureau of Medicine and Surgery Department of the Navy Washington, D.C. 20375
(2)	Technical Reference Library Naval Medical Research Institute National Naval Medical Center Bethesda, Maryland 20014
(1)	Office of Naval Research Branch Office 495 Summer Street Boston, Massachusetts 02210
(1)	Office of Naval Research Branch Office 536 South Clark Street Chicago, Illinois 60605
(1)	Office of Naval Research Branch Office 1030 East Green Street Pasadena, California 91106
(1)	Commanding Officer Naval Medical Research Unit No. 2 Box 14 APO San Francisco 96263
(1)	Commanding Officer Naval Medical Research Unit No.3 FPO New York 09527
(1)	Officer in Charge Submarine Medical Research Laboratory Naval Submarine Base, New London Groton, Connecticut 06342
(1)	Scientific Library Naval Medical Field Research Laboratory Camp Lejeune, North Carolina 28542
(1)	Scientific Library Naval Aerospace Medical Research Institute Naval Aerospace Medical Center Pensacola, Florida 32512

(1) Commanding Officer
Naval Air Development Center
Attn: Aerospace Medical Research Department
Warminster, Pennsylvania 18974

(1) DIRECTOR
Naval Biosciences Laboratory
Building 844
Naval Supply Center
Oakland, California 94625

(1) Commander, Army Research Office
P.O. Box 12211
Research Triangle Park
North Carolina 27709

(1) DIRECTORATE OF LIFE SCIENCES
Air Force Office of Scientific Research
Bolling Air Force Base
Washington, D.C. 20332

(1) Commanding General
Army Medical Research and Development Command
Forrestal Building
Washington, D. C. 20314

(1) Department of the Army
U. S. Army Science and
Technology Center - Far East
APO San Francisco 96328

(1) Assistant Chief for Technology
Office of Naval Research, Code 200
800 N. Quincy Street
Arlington, Virginia 22217